Estimating Forage Crop Production:
a Technique Adaptable to Remote Sensing*

ROBERT J. REGINATO, SHERWOOD B. IDSO, AND RAY D. JACKSON

U. S. Water Conservation Laboratory, 4331 East Broadway, Phoenix, Arizona 85040

The "stress degree day" technique for estimating yields of wheat from canopy and air temperature measurements is extended to handle forage production. It was found to be valid in its extended form for four sequential cuttings of alfalfa grown at Phoenix, Arizona, over the period May – August 1976.

Introduction

Many scientists have devoted considerable research efforts to developing techniques of crop yield estimation that can be utilized in a remote sensing context (Thomas et al., 1967; Hiler and Clark, 1971; Hammond, 1975, Morain and Williams, 1975; Earth-Sat Corp. 1976). We are no exception. Having recently described two distinct approaches to predicting yields of grain crops, one based on repeated monitoring of reflected solar radiation (Idso et al., 1977b) and the other upon the similar assessment of emitted thermal radiation (Idso et al., 1977a), we present here the first extension of the latter approach to include forage crop production. Specifically, we report on an experiment conducted this past summer at Phoenix, Arizona, that was designed to determine if there was a relationship between the dry matter production of alfalfa (*Medicago sativa* L.) and the "stress degree day" parameter we introduced in our original work with wheat (*Triticum durum* Desf.) (Idso et al., 1977a,b).

In its most simple form, the stress degree day parameter is defined as the midafternoon (about 2 p.m.) crop canopy – air temperature differential ($T_C - T_A$). We had previously found that the summation of daily values of this temperature differential over the period of wheat head growth was an inverse linear function of final grain yield (Y). That is, we found for wheat that

$$Y = \alpha - \beta \left(\sum_{i=b}^{e} \text{SSD}_i \right)$$

where k is a constant and b and e marked the beginning and end of the period of active head growth. Our hypothesis for the alfalfa experiment was that similar relation would hold for stress degree day summations over the period of vegetation growth from one cutting to the next.

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To test the idea, we initiated a program of daily T_C and T_A measurement between 1345 and 1415 at two sites within each of four differentially irrigated fields. Canopy temperature measurements were made with a 20° field-of-view Barnes[1] PRT-5 infrared thermometer that was hand-held so as to look in a downward direction perpendicular to the crop surface, as well as in the four cardinal compass directions at about a 45° angle to the crop surface. After each cutting the downward-looking radiometer saw both soil and vegetation, whereas the radiometer held at 45° saw nearly all vegetation. Just prior to cutting, both radiometers were viewing essentially all vegetation. All surface temperatures reported herein are effective blackbody temperatures; that is, the crop canopy is assumed to have an emissivity of unity. Although this is not precisely true, it is very close to reality, and the approximation does not alter in any material way the nature of the conclusions reached. Air temperature measurements were made at the same sites as the crop canopy temperature measurements by means of a portable aspirated psychrometer. Both types of measurements were acquired Monday through Friday of each week. For computational completeness in making stress degree day summations, we set Saturday $T_C - T_A$ values equal to those of the preceding Friday, and Sunday values equal to those of the following Monday.

Yield data were acquired at each of the eight measurement sites following cuttings on 18 May, 22 June, 15 July, and 24 August. We collected material from 2-m-wide swaths running perpendicular to the windrows across the entire widths of the fields, which ranged from 20 to 40 m. These samples were manually weighted *in situ* and subsamples taken to determine moisture content. Final results were expressed in terms of gm dry matter produced per m^2.

Due to an initial experimental oversight, air temperatures were not recorded during the first three vegetative growth periods. Thus, only one set of forage production data was available to test the basic form of the stress degree day concept applied to alfalfa. Fig. 1 graphically presents this test for all eight sites, based upon canopy temperatures obtained by viewing the canopy with the infrared thermometer at about a 45° angle from the horizontal. A similar analysis based upon canopy temperatures obtained by viewing straight down gives results which were equally good, if not slightly better: correlation coefficient of 0.92.

To fully utilize results from all four cuttings (in the absence of air temperature data for the first three vegetative growth periods), a second analysis was performed. Yields from the two measurement sites in the continually well-watered plot, plot 4, were averaged together, and the six remaining sites were compared to this standard. That is, *yield reductions* of the two measured sites in plots 1, 2, and 3 *relative to plot 4* were plotted against afternoon canopy

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[1] Trade names and company names are included for the benefit of the reader and imply no endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.
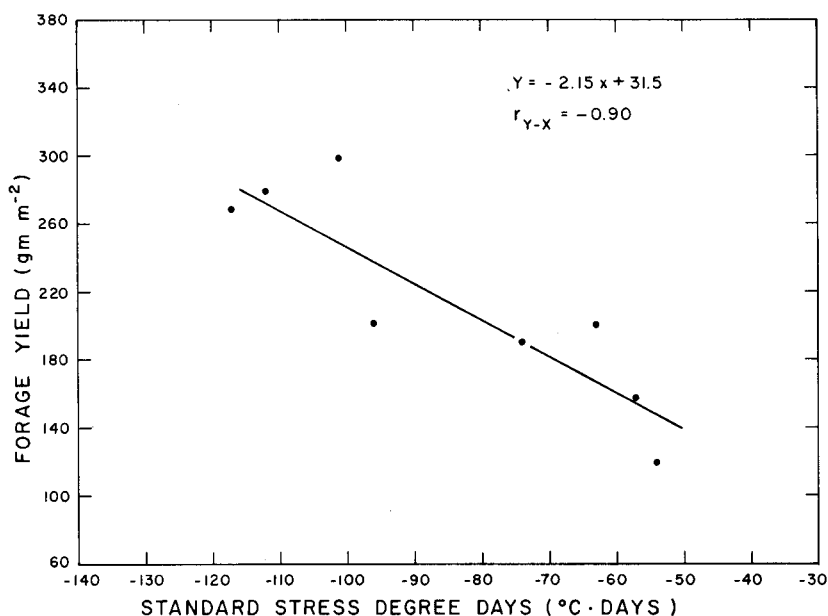
FIG. 1 Dry matter production of four fields of alfalfa (two sites each) grown at Phoenix, Arizona in Aug. 1976 vs. stress degree days accumulated by plants at each site over the last 11 days prior to cutting.

temperatures of plots 1, 2, 3 *in excess of those of plot 4* (equivalent to excess stress degree days for common air temperatures) for the common base time of all days preceding each cutting. The base of 11 days was used as it was the shortest period of alfalfa grown between irrigation and harvest for the four cuttings. It is observed in Fig. 2 that the slope of this relation is essentially identical in absolute magnitude to that of Fig. 1, indicating that the relation developed in Fig. 1 would be valid for all four periods of growth. Negative values mean that the yields from certain plots exceeded the yield from plot 4 at comparable times. Again, canopy temperatures obtained by viewing straight down with the infrared thermometer gave equally good results. The correlation coefficent with the

We conclude from these findings that the stress degree day concept of crop yield estimation may apply equally as well to forage crops as to grain crops. Being adaptable as it is to remote sensing (requiring only surface and air temperature data), its further study and refinement in other locations and on other crops could lead to its rapid incorporation into operational aircraft and satellite programs for conserving our dwindling land, water, and energy resources and for coordinating international efforts to obtain global estimates of crop yields.
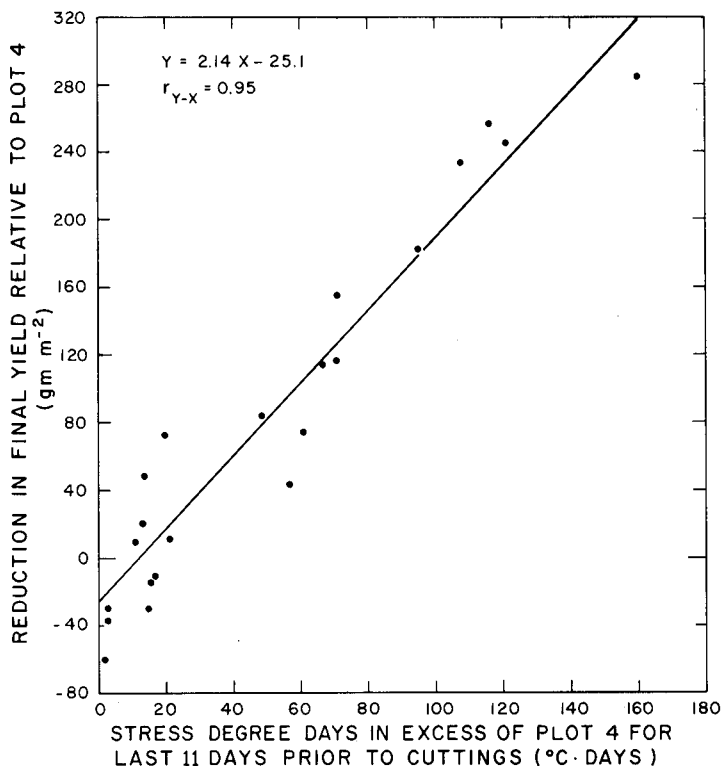
FIG. 2 Reduction in dry matter production of three fields of alfalfa (two sites each) grown at Phoenix, Arizona in May, June, July, and Aug. 1976 (4 separate cuttings) relative to that produced by a fourth well-watered field (Plot 4) vs. the stress degree days accumulated by plants at each site in excess of those accumulated by plants in Plot 4.

experiment, and for the special services of C. W. Fitzgibbon to help manage the plots.

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